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Evaluation of a Programmable Voltage-Controlled MEMS Oscillator, Type SiT3701, Over a Wide Temperature Range

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Scope

Semiconductor chips based on MEMS (Micro-Electro-Mechanical Systems) technology, such as sensors, transducers, and actuators, are becoming widely used in today's electronics due to their high performance, low power consumption, tolerance to shock and vibration, and immunity to electro-static discharge. In addition, the MEMS fabrication process allows for the miniaturization of individual chips as well as the integration of various electronic circuits into one module, such as system-on-a-chip. These measures would simplify overall system design, reduce parts count and interface, improve reliability, and reduce cost; and they would meet requirements of systems destined for use in space exploration missions. In this work, the performance of a recently-developed MEMS voltage-controlled oscillator was evaluated under a wide temperature range. Operation of this new commercial-off-the-shelf (COTS) device was also assessed under thermal cycling to address some operational conditions of the space environment.

Test Procedure

The device investigated in this work comprised of a SiTime Corporation SiT3701 MEMS voltage-controlled oscillator (VCO). This programmable device combined a highly robust and reliable MEMS resonator with advance analog circuits to provide a flexible and programmable solution for clock synchronization applications [1]. It provided a 0.5% linear pull range, representing significant improvement over the 5% - 10% linearity offered by quartz-based VCO's. This enhancement allows system designers to simplify the clock synchronization algorithm, improve system lock time and provide better system stability [1]. Some of the manufacturer's specifications for this MEMS VCO are shown in Table I [1].

Table I. Specifications of SiT3701 MEMS voltage-controlled oscillator [1].

Parameter	**Symbol**	**SiT3701AI-32-25A-80.00000**
Supply Voltage (V)	Vdd	2.25 to 2.75
Supply Current (mA)	Idd	8 to 10
Programmed Frequency (MHz)	f	80
Control Voltage (V)	Vin	0 to 1.75
Duty Cycle (%)	D	40 to 60
Rise/Fall Time (ns)	Tr, Tf	1 to 2
Operating Temperature (°C)	T(oper)	-40 to +85
Package		4-pin Plastic SMD
Lot Number		5032F

The oscillator chip was examined for operation between -180 °C and +85 °C. Performance characterization was obtained in terms of output frequency and supply current at specific test temperatures. The duty cycle of the output signal along with its rise and fall time characteristics were also recorded. All of these properties were also obtained as a function of the input "control" voltage (Vin). During these tests, a temperature rate of change of 10 °C per minute was used, and a soak time of at least 20 minutes was allowed at every test temperature. Restart operation capability of the device under extreme temperatures was also investigated. In addition, the effects of thermal cycling under a wide temperature range on the operation of this part were determined. The device was exposed to a total of 12 cycles between -180 °C and +85 °C. Following cycling, measurements were then performed at the test temperatures of +22, -180, and +85 °C at selected Vin values. Figure 1 shows the circuit board populated with the MEMS VCO chip along with a couple of filter capacitors.

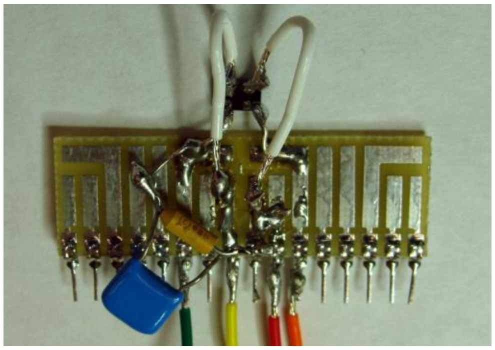


Figure 1. Oscillator chip and filter capacitors mounted on circuit board.

Test Results

Temperature Effects

The output waveform of the MEMS voltage-controlled oscillator at room temperature is shown in Figure 2, and the VCO output frequency at various control voltages is shown as a function of temperature in Figure 3. Below -180 °C the oscillator became unstable. Between -100 °C and -180 °C, control of frequency was unreliable. Figure 4 shows frequency vs. control voltage at various temperatures. Figure 4 indicates that temperature has some effect on frequency, namely that between +85 °C and -50 °C for a decrease in temperature there is a decrease in frequency. Figure 5 shows that as temperature decreased from -50 °C to -100 °C for a given control voltage there was an increase in frequency. It is important to note that this industrial-grade device was only specified to - 40 °C as the low end of operating temperature. In addition, the anomalies exhibited in the frequency response at the test temperature below - 100 °C were transitory in nature as recovery took place upon exposing the device to temperatures warmer than -100 °C.

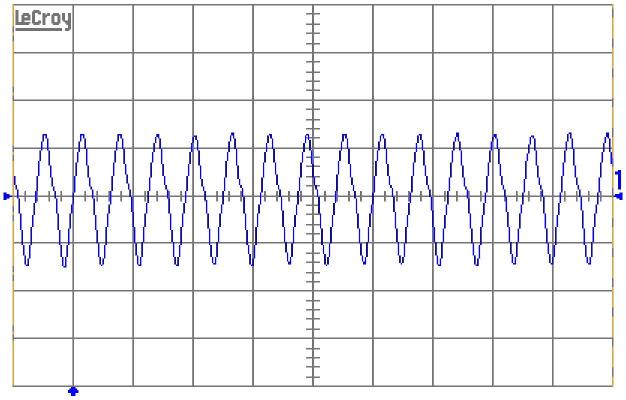


Figure 2. Output waveform of the MEMS VCO. (Horiz: 20 ns/div; Vert: 0.5 V/div)

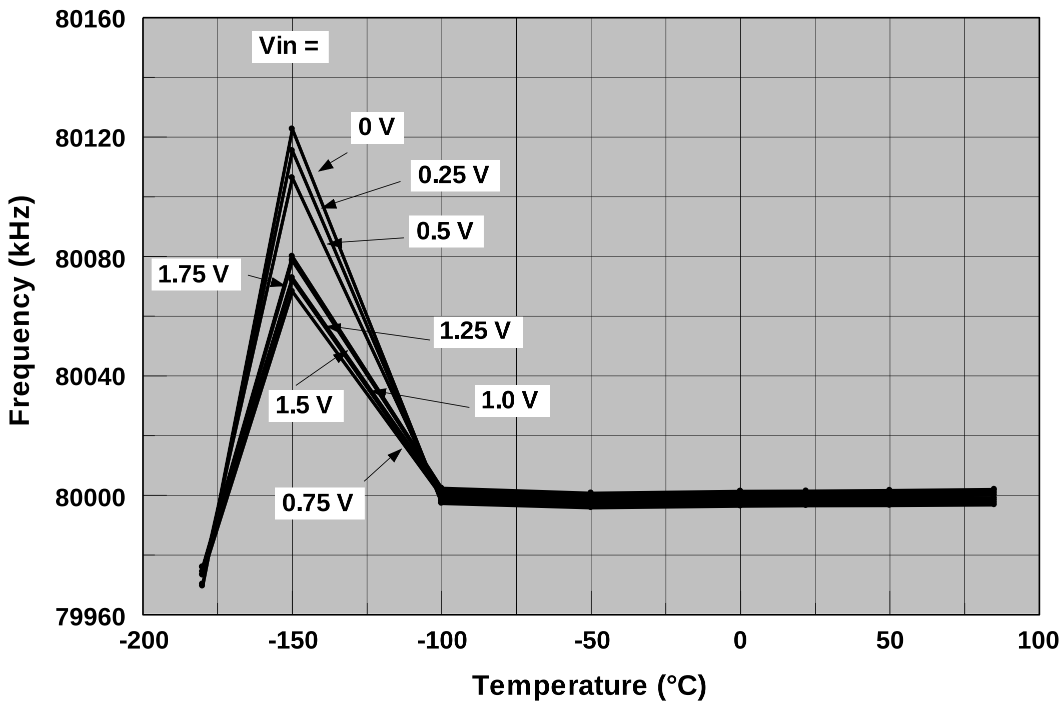


Figure 3. Oscillator frequency versus temperature for various control voltages.

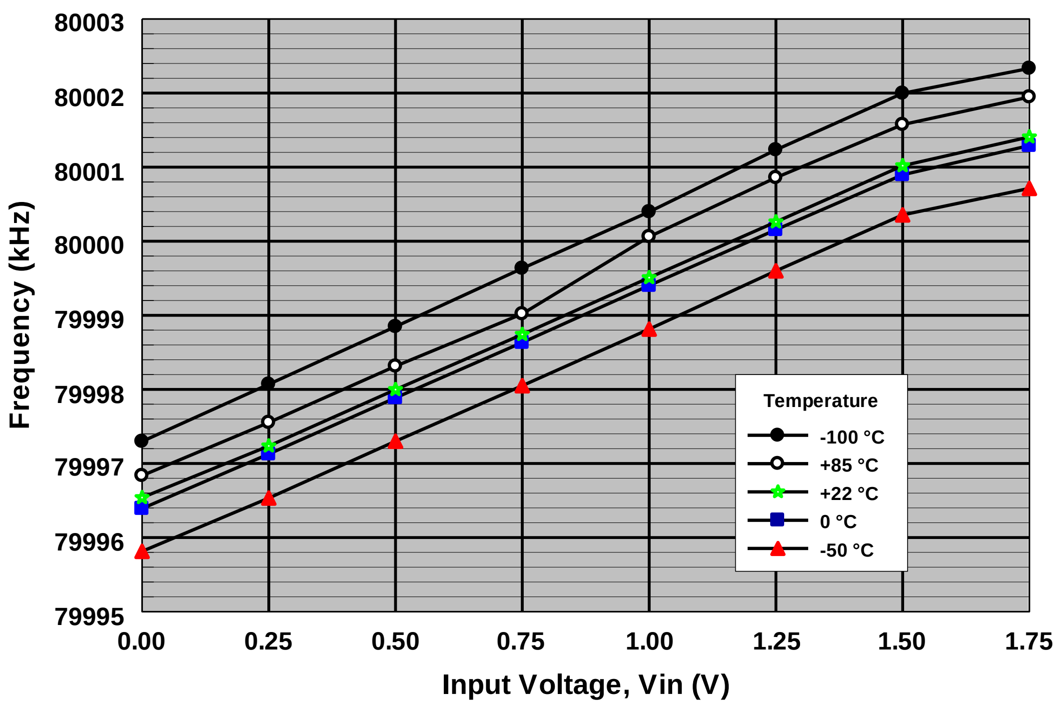


Figure 4. Oscillator frequency as a function of control voltage at various temperatures.

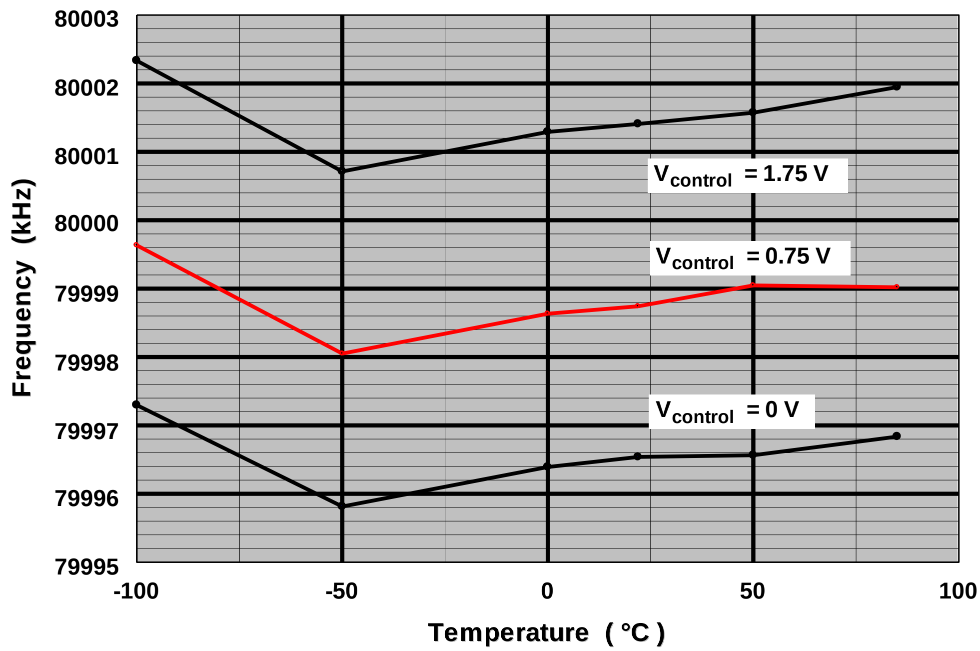


Figure 5. Oscillator frequency as a function of temperature for three control voltages.

The duty cycle of the MEMS VCO output signal did not display any significant change over the test temperature range as its value retained a value around 55 % throughout the test temperature range between -180 °C and +85 °C, as shown in Figure 6.

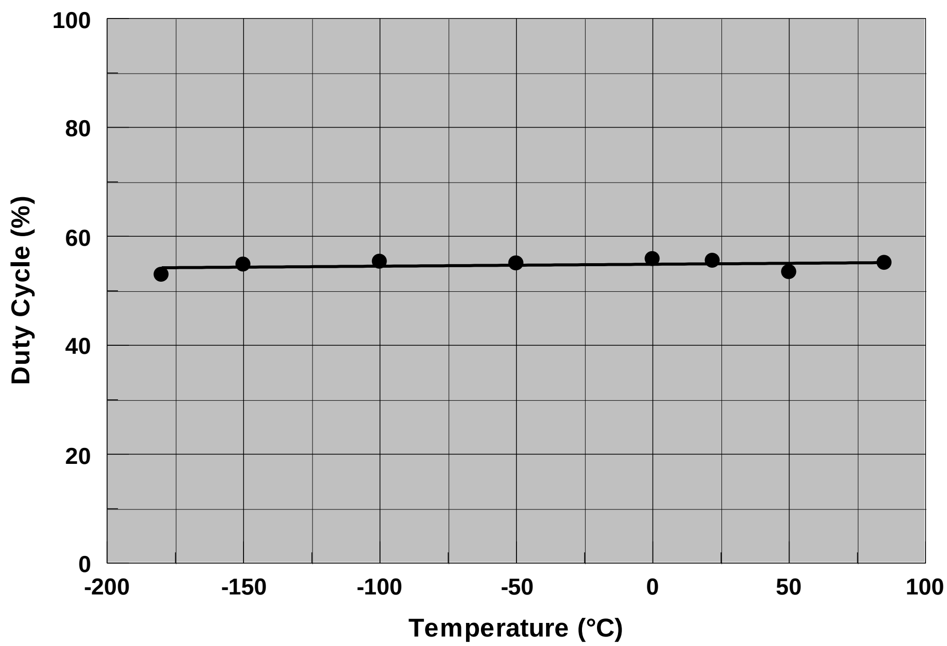


Figure 6. Duty cycle of the VCO output versus temperature.

The rise and fall times of the output signal underwent very slight variation with temperature. While both of these characteristics were steady between -50 °C and +85 °C, their values experienced similar trivial fluctuation as temperature was set to below -50 °C. Figure 7 displays these characteristics as a function of the test temperature.

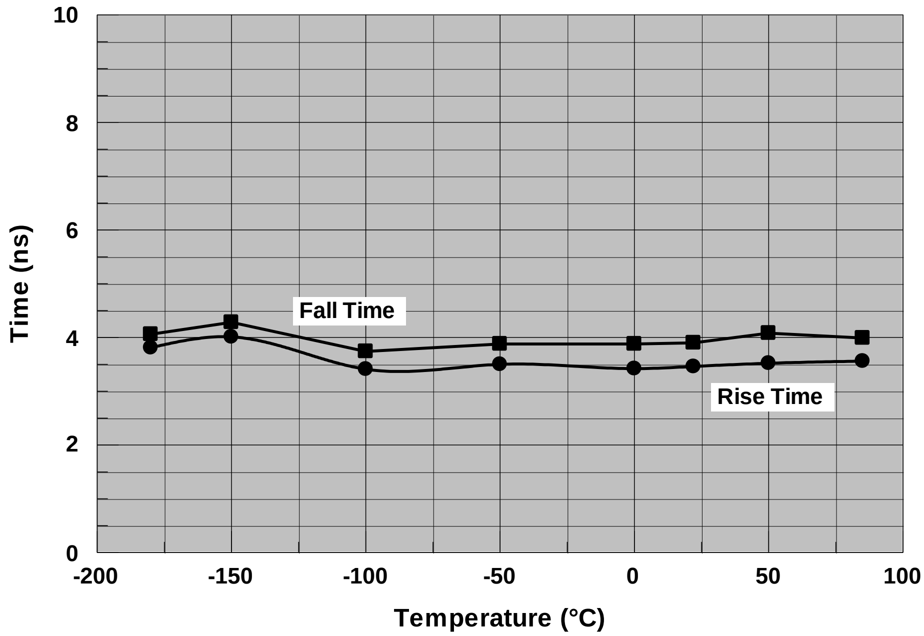


Figure 7. Rise and fall times of output signal versus temperature.

Similar to the rise and fall times, the supply current of the MEMS voltage-controlled oscillator exhibited no dependency on temperature in the range of -50 °C to +85 °C as it sustained a constant value of about 10 mA, as shown in Figure 8. At temperatures below -50 °C, the current initially decreased very slightly but began to increase as temperature was decreased further. The onset of the current increase seemed to develop at about -110 °C; reaching a value of about 13.75 mA at the extreme cryogenic temperature of -180 °C.

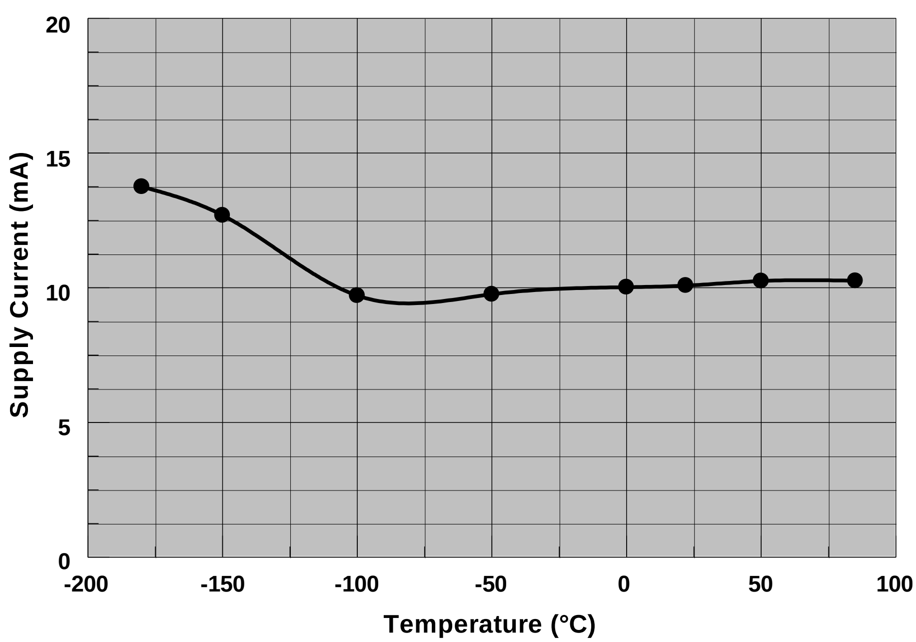


Figure 8. VCO supply current as a function of temperature.

Re-Start at Extreme Temperatures

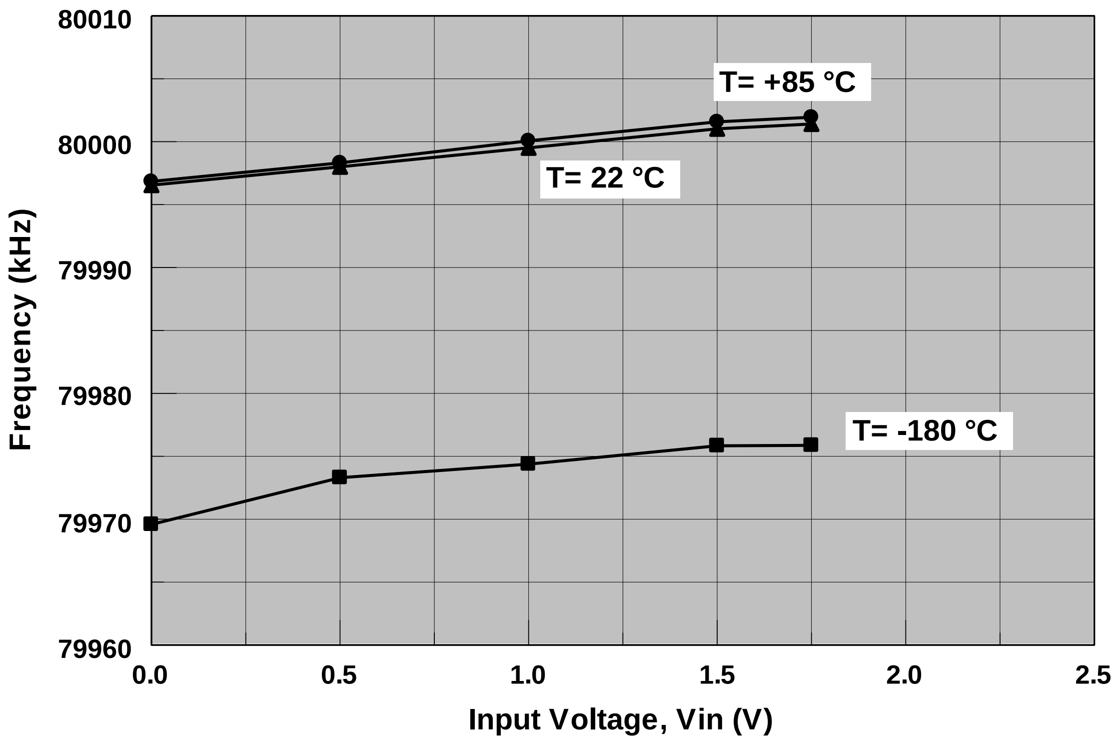
Restart capability of this SiT3701 MEMS voltage-controlled oscillator was investigated at the extreme test temperatures at which stable operation was maintained, i.e. -180 °C and 85 °C. The oscillator chip was allowed to soak separately at those two temperatures, with electrical power off for at least 20 minutes. Power was then applied to the circuit, and measurements of the oscillator's output waveform characteristics and frequency were recorded. The voltage-controlled oscillator circuit was able to operate successfully at either of the two extreme temperatures and the results obtained were similar to those obtained earlier at these respective temperatures.

Effects of Thermal Cycling

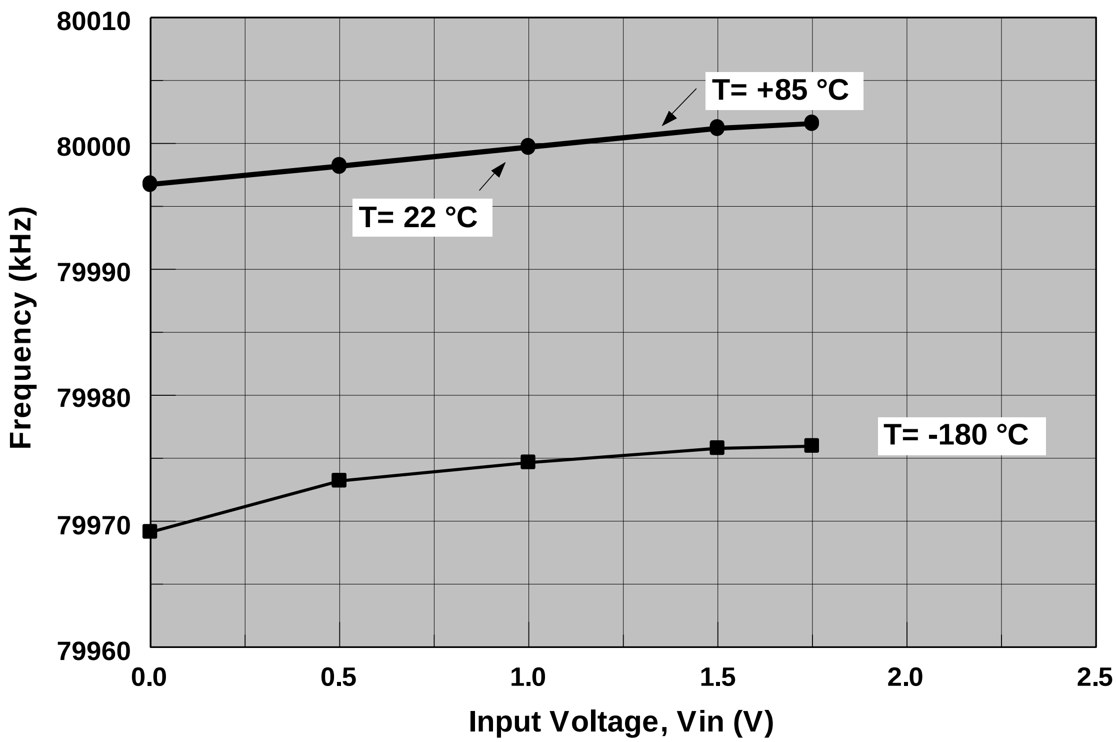
The effects of thermal cycling on the performance of this MEMS VCO were investigated by subjecting the SiT3701 oscillator chip to a total of 12 cycles between -180 °C and +85 °C at a temperature rate of 10 °C/minute and a soak time of 20 minutes at the extreme temperatures. Measurements on the characteristics of the oscillator circuit were then taken at the three temperatures of +22, +85, and -180 °C. A comparison of the output frequency as a function of control voltage at these temperatures for pre- and post-cycling conditions is shown in Figure 9. It can be clearly seen that the post-cycling frequency/voltage curves at any given temperature were nearly the same as those obtained prior to cycling. Similar results were obtained for the output signal characteristics as well as the circuit's supply current. Table II lists post-cycling data of these characteristics along with those obtained prior to cycling. These results indicate that this MEMS VCO oscillator did not undergo any significant changes in its operational characteristics due to this limited cycling. The thermal cycling also appeared to have no effect on the structural integrity of the device as no packaging damage was noted upon inspection.

Table II. Pre- and post-cycling characteristics of the oscillator with Vin = 1 V.

T(°C)	Cycling	f (kHz)	Duty cycle (%)	T_{rise} (ns)	T_{fall} (ns)	I_S (mA)
+22	pre	79999.508	55.5	3.46	3.90	10.08
	post	79999.618	50.1	3.47	3.84	10.13
-180	pre	79974.377	52.9	3.81	4.06	13.75
	post	79974.657	50.9	3.63	3.88	13.71
+85	pre	80000.062	55.1	3.56	3.99	10.26
	post	79999.791	51.0	3.46	4.0	10.43



Pre-cycling



Post-cycling

Figure 9. Output frequency for pre- and post-cycling as a function of control voltage.

Conclusions

The performance of a recently-developed MEMS voltage-controlled oscillator was evaluated under a wide temperature range. The effects of thermal cycling on the operation of this SiT3701 oscillator chip and restart capability at extreme temperatures, which are typical of space operational requirements, were also investigated. The oscillator was characterized in terms of its output frequency stability, output signal rise and fall times, duty cycle, and supply current at various control voltages. As temperature was decreased from +85 °C to -50 °C, there was some decrease in frequency. As temperature changed from -50 °C to -100 °C, frequency increased. Below -100 °C operation became unreliable, and below -180 °C, the oscillator became unstable. It should be noted that the device was only specified to - 40 °C as the low end of operating temperature. The anomalies that occurred below -100 °C were only temporary as recovery took place upon applying test temperatures of -100 °C or warmer. The SiT3701 MEMS voltage-controlled oscillator was also able to re-start at both -180 °C and +85 °C, and it exhibited no change in performance due to the thermal cycling. In addition, no physical damage was observed in the packaging material due to extreme temperature exposure and thermal cycling. Temperature had some effect on frequency; therefore use of the device will depend upon frequency stability requirements.

References

[1]. SiTime Corporation "SiT3701 Smallest Programmable VCMO Voltage controlled MEMS Oscillator - Preliminary Information", Data Sheet, Rev. #1.3, March 2009, http://www.sitime.com.

Acknowledgements

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